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DETERMINATION OF BIAXIAL CREEP STRENGTH OF T-111 TANTALUM ALLOY

SEMI-ANNUAL REPORT

Period: March 8, 1967 to September 8, 1967

EDITED BY L. B. ENGEL, JR.

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3-9437

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

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DETERMINATION OF BIAXIAL CREEP STRENGTH OF T-111 TANTALUM ALLOY

I. INTRODUCTION

This report covers the period from March 8, 1967 to September 8, 1967, of a program to document the creep behavior of seamless and welded and reworked T-111 alloy tubing under a biaxial state of stress, and to evaluate the effects of stress on the corrosion behavior of T-111 alloy with potassium. Potassium refluxing capsules of seamless and welded and reworked T-111 alloy tubing are to be tested under conditions which will result in one to five percent equivalent uniaxial strain during a 5000-hour exposure. It is anticipated that the capsule test temperature will be in the range of 2100° to 2400°F. The capsule walls will be reduced in the potassium liquid region and in the vapor condensing region to provide gauge sections where the extent of creep can be measured. The testing will be done in a manner similar to that developed under an earlier NASA contract[1] (NAS 3-6012).

II. SUMMARY

An order for seamless and welded and reworked 1.5-inch OD x 0.100-inch wall T-111 alloy tubing from which the capsules will be fabricated was placed with the Superior Tube Company. Delivery of the seamless and welded and reworked 1.5-inch OD x 0.100-inch wall T-111 alloy tubing is scheduled for January 8, 1968.

Minor design changes in the test facility which will be used for this program and which was previously used for NASA Contract NAS 3-6012 have been completed.

The detailed design of the potassium pressure transducer to be used to measure the potassium pressure in the refluxing capsules during testing was completed and approved by the NASA Program Manager; machining of the components has been completed and assembly of the pressure transducer is now underway.

An error analysis of the test facility and the stress-strain relationships utilized in calculating equivalent uniaxial values from biaxial data has been completed.

III. PROGRAM STATUS

MATERIALS PROCUREMENT

An order for 48 inches of 1.5-inch OD x 0.100-inch wall seamless and welded and reworked T-111 alloy tubing was placed with the Superior Tube Company, Norristown, Pennsylvania. Both the seamless and welded and reworked T-111 alloy tubing will be made from the same heat of T-111 alloy. The seamless tubing will be made utilizing standard tube reducing techniques. The welded and reworked tubing will be made by making an electron beam weld pass along the entire length of the seamless 2.0-inch OD x 0.250-inch thick wall tube shell prior to reduction to final size. Subsequently, the weld will be clearly marked, benched, and ultrasonically inspected. The inside of both tube shells will then be honed to a surface finish of less than 16 rms by Detroit Diameters, South Hills, Michigan. After honing, the welded tube shell will be reduced to final size in the same manner and at the same time as the seamless tubing. Delivery of the 2.0-inch OD x 0.250-inch wall T-111 alloy tube shells to the General Electric Company, SPPS for welding and honing prior to the final reduction is scheduled for October 2, 1967. The delivery of the finished tubing from Superior Tube Company is scheduled for January 8, 1968.

TEST FACILITY

The same test facility as was used for testing capsules made from D-43 alloy on NASA Contract NAS 3-6012[1] will be used for the testing of the T-111 alloy capsules, Figures 1 through 3. Minor design changes in the facility have been completed to allow for installation of a potassium pressure transducer which will be attached to the T-111 alloy capsule. A pressure transducer, to measure the potassium pressure within the capsule, was not used on the previously tested D-43 alloy capsules.

Fabrication of the modified test facility hardware has been completed and is ready for installation into the previously used test facility.

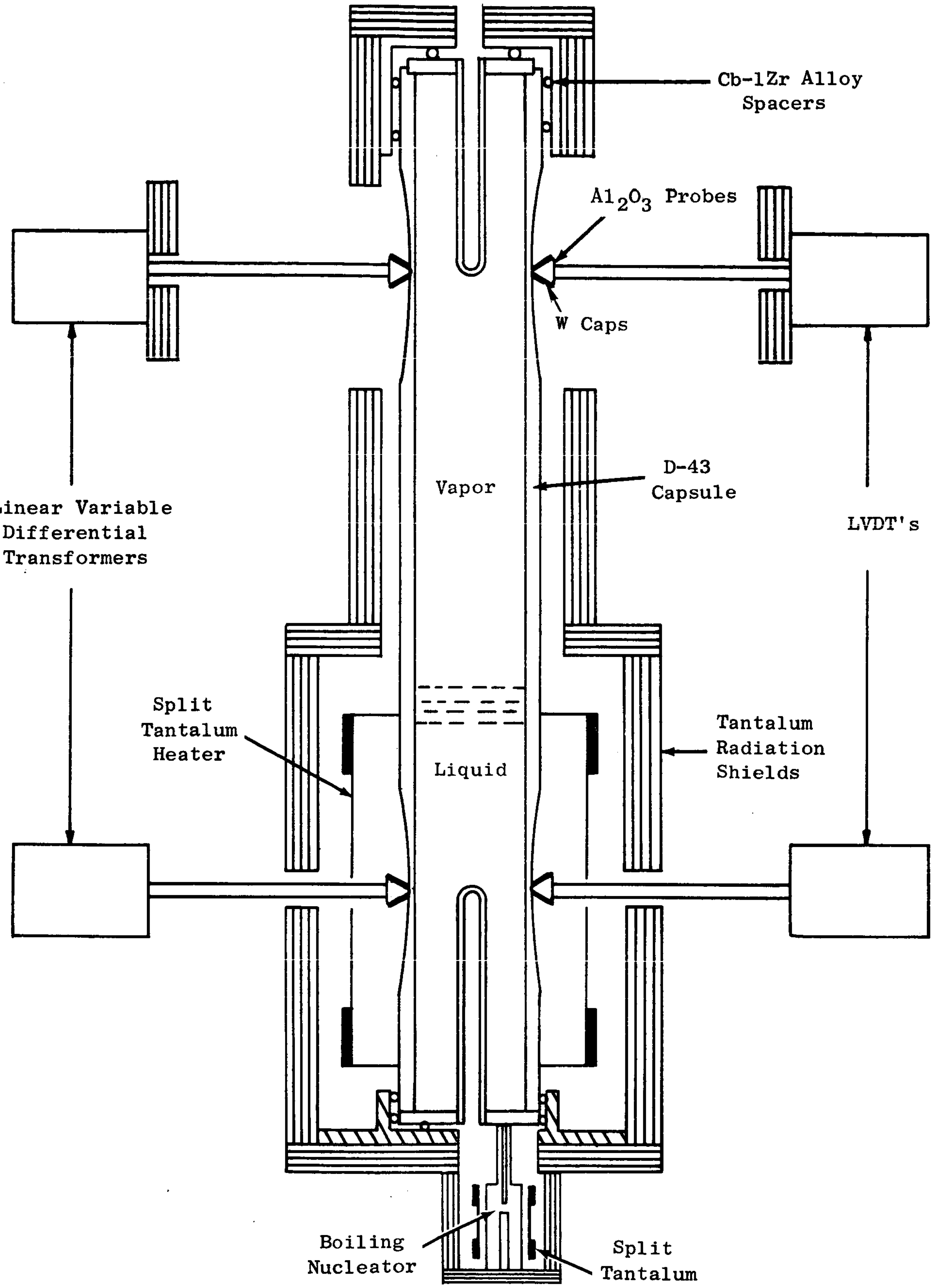

Figure 1. Schematic Arrangement Utilized for Measuring Biaxially Induced Creep in the Thin-Wall Sections of D-43 Alloy Reflux Corrosion Capsules on NASA Contract NAS 3-6012.

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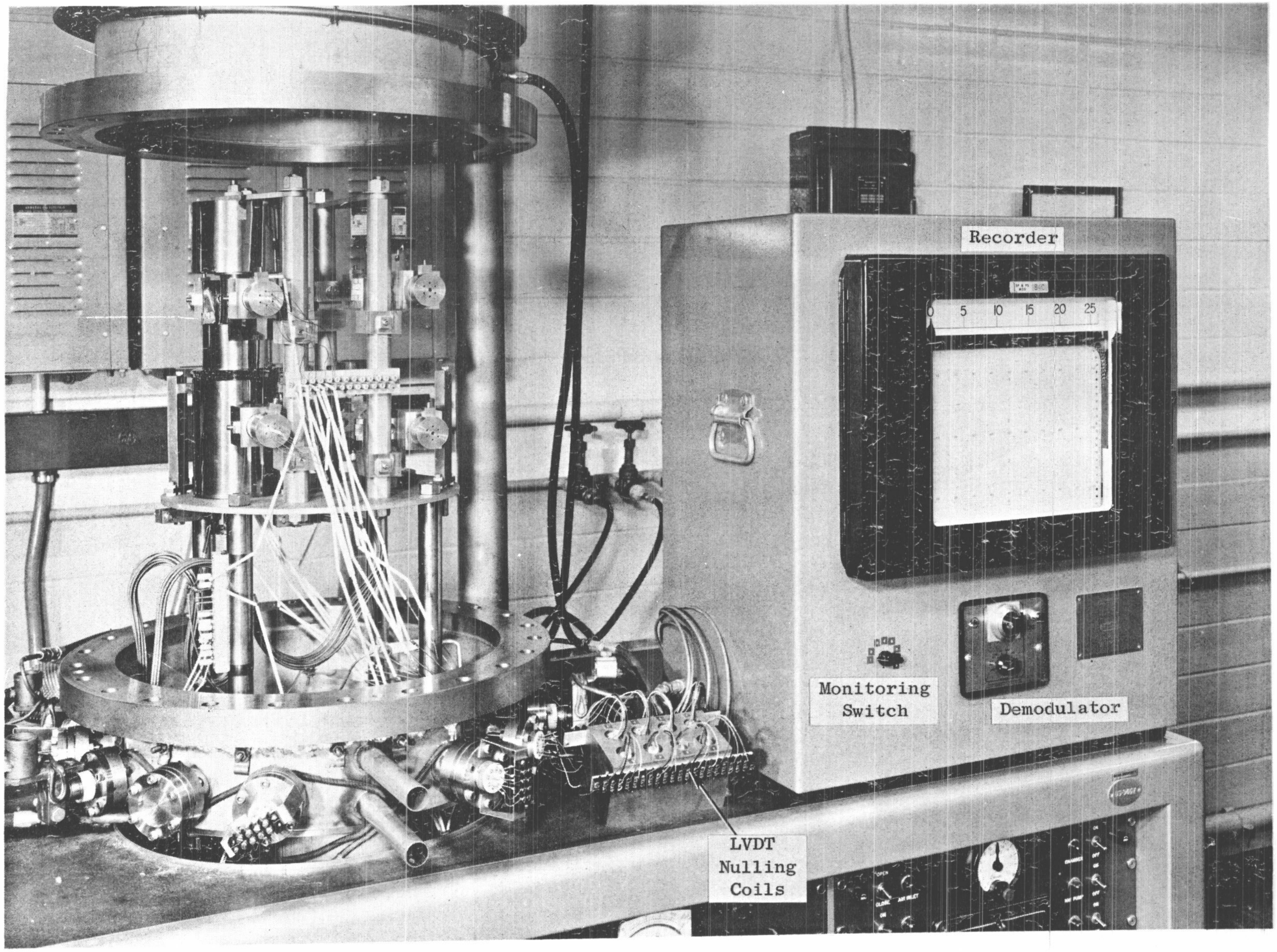

Figure 2. Test Facility Utilized to Measure Biaxially Induced Creep in D-43 Alloy Reflux Corrosion Capsules on NASA Contract NAS 3-6012.

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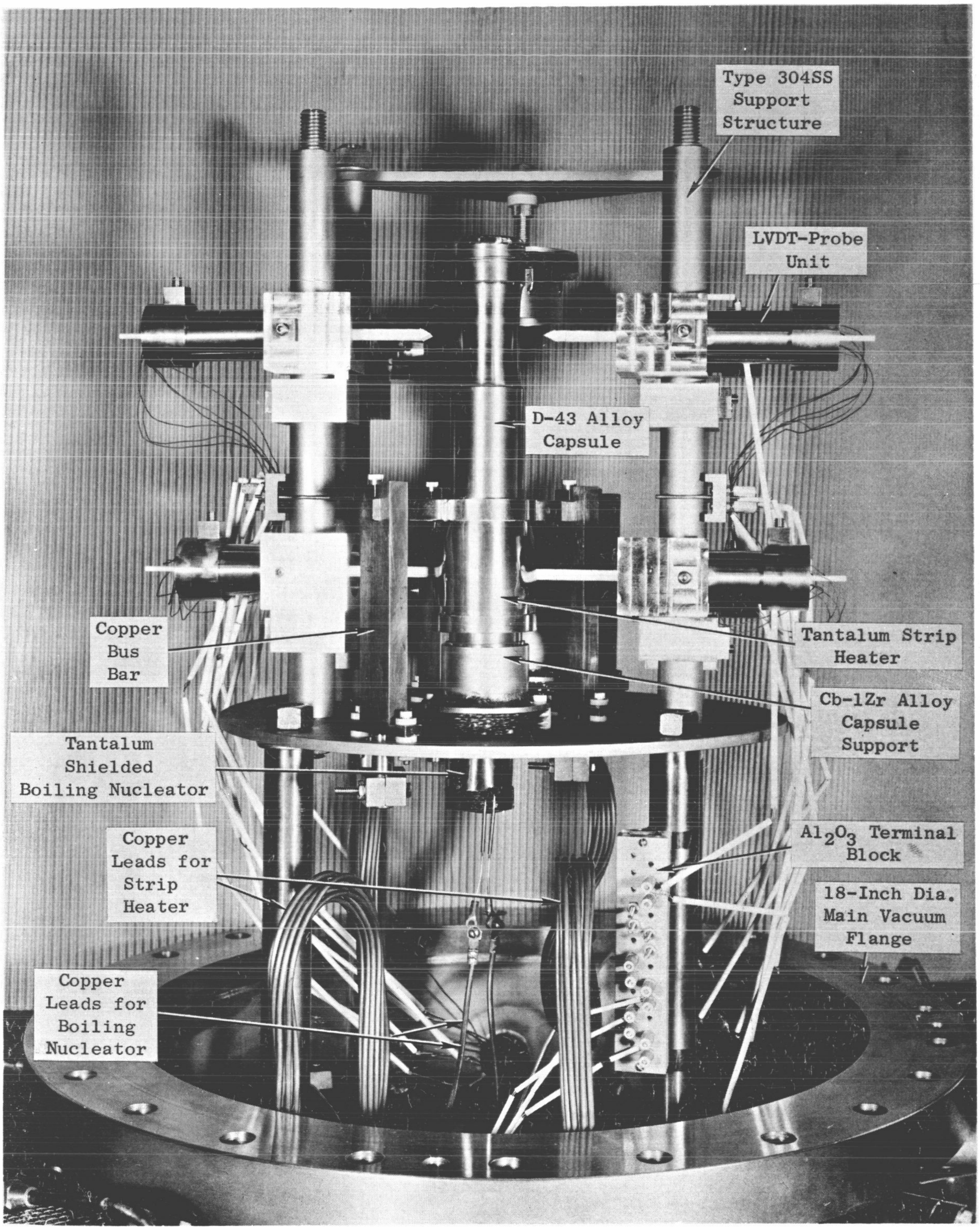


Figure 3. Test Facility Utilized to Measure Biaxially Induced Creep in D-43 Alloy Reflux Corrosion Capsules on NASA Contract NAS 3-6012.

C1290-3

POTASSIUM PRESSURE TRANSDUCER

The design of the potassium pressure transducer to be used for measuring the potassium pressure within the capsule during testing is very similar to the design of the pressure transducer used by the U. S. Naval Research Laboratory[2] to determine the vapor pressure of potassium as a function of temperature. The detailed design of the pressure transducer has been completed and has been received and approved by the NASA Program Manager and personnel from the U. S. Naval Research Laboratory.

The pressure transducer design is shown in Figure 4. A schematic of the pressure system to be used with the pressure transducer is shown in Figure 5. The pressure transducer works on a manual null-balance principle with high purity argon gas pressure being applied to one side of the transducer diaphragm and opposing the vapor pressure of the potassium which exerts a force on the opposite side of the pressure transducer diaphragm. By pre-setting the terminal in contact with the diaphragm such that when the pressure on one side of the diaphragm is in balance with the opposing pressure on the other side of the diaphragm, the contact is slightly open. The open circuit can be used to indicate when the argon pressure just equals the potassium vapor pressure in the test capsule. Measurement of the argon pressure with an accurate pressure gauge is a direct indication of the potassium vapor pressure on the opposing side of the diaphragm and, therefore, within the test capsule. The argon gas pressure is controlled with two Hoke needle valves (Model TY445), one to allow argon to enter the system, and the second to allow argon to bleed off into a vacuum. The total volume of the gas system is increased by adding a one-liter pressure cylinder in order to provide greater control in making small manual pressure adjustments.

Figure 6 illustrates the test capsule design, which is similar to that previously utilized under NASA Contract NAS 3-6012, with the pressure transducer in place. Machining of the pressure transducer components at Precision Mechanics, Inc., Newtown, Ohio has been completed, Figure 7, and the assembly of two pressure transducers has been initiated.

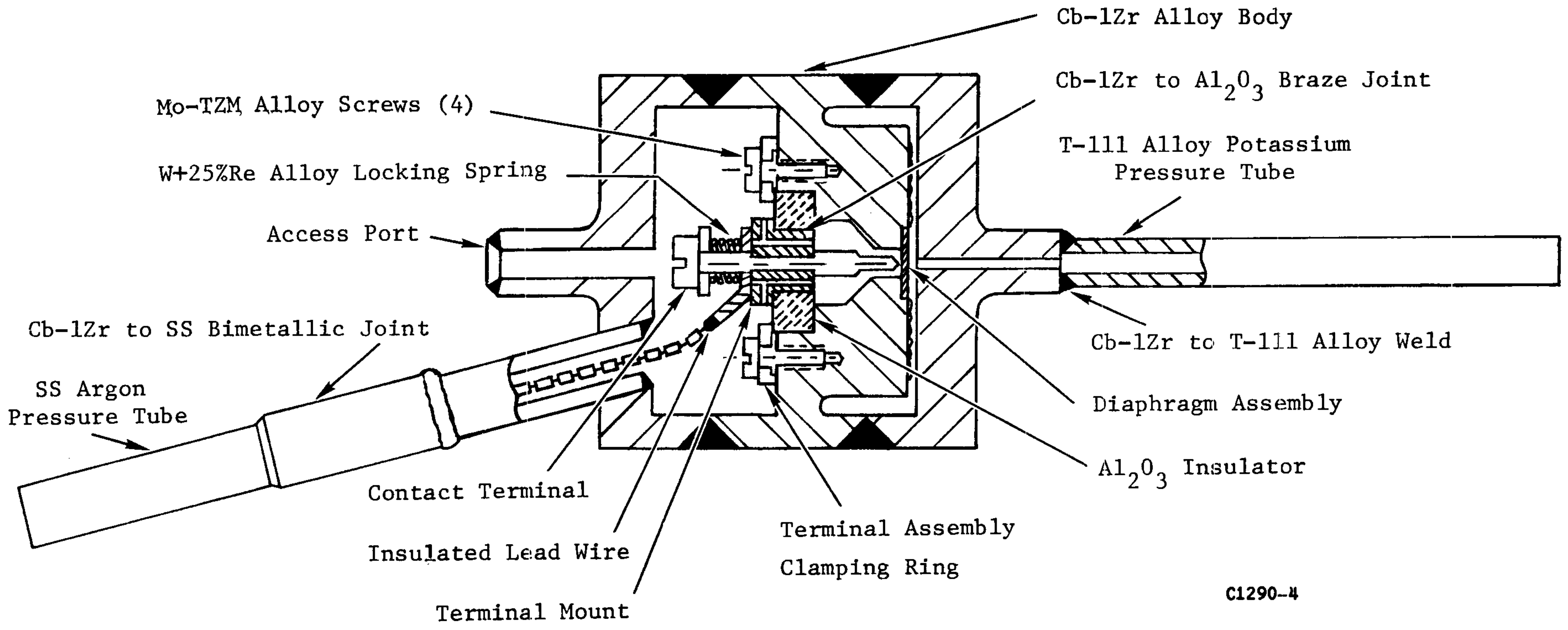
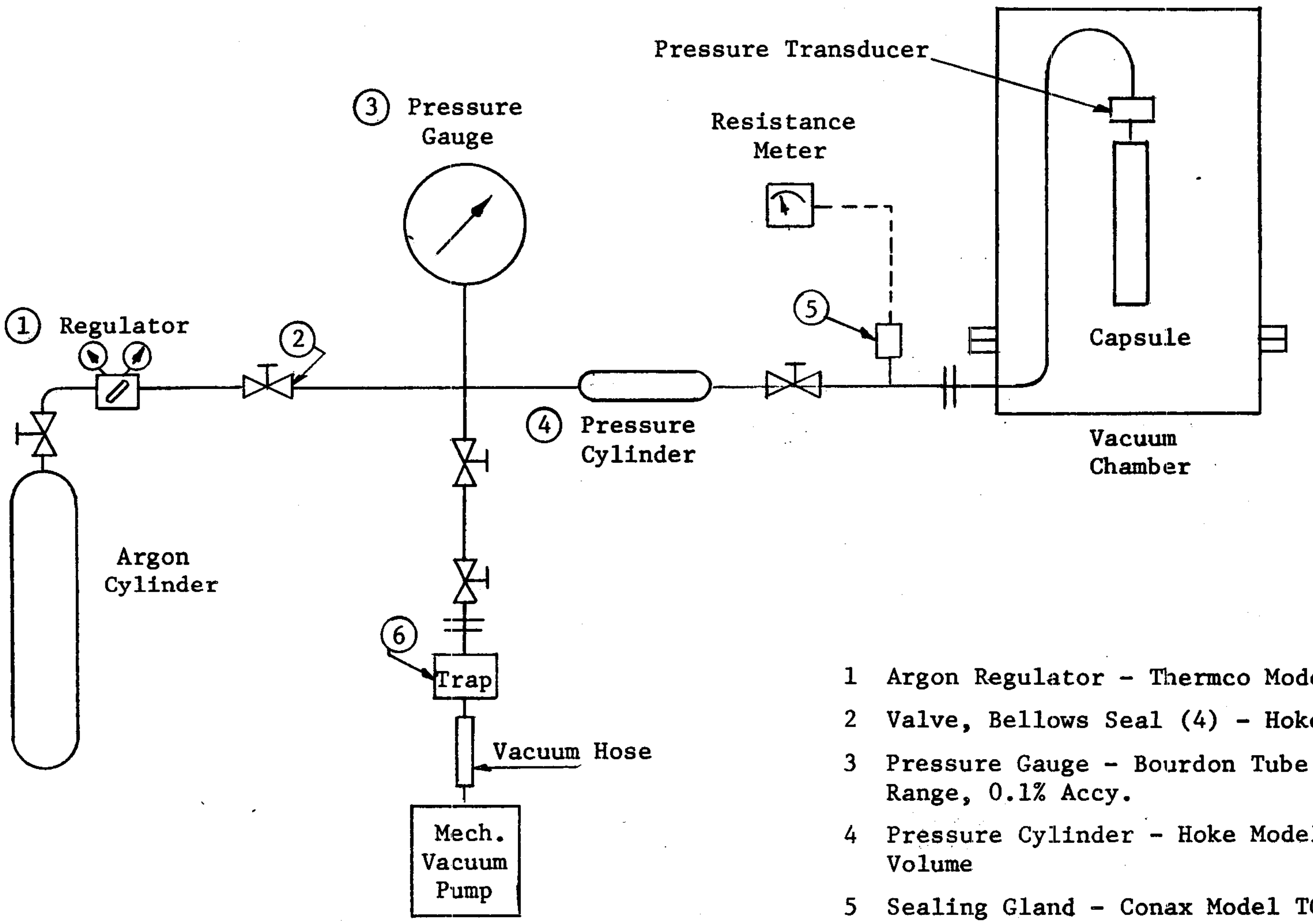


Figure 4. Design of T-111 Alloy Biaxial Creep Capsule Pressure Transducer.



1 Argon Regulator - Thermco Model 3504-600 all SS.
2 Valve, Bellows Seal (4) - Hoke Model Ty445
3 Pressure Gauge - Bourdon Tube Type, 500 psia Range, 0.1% Accy.
4 Pressure Cylinder - Hoke Model 8HD 1000, 1 Liter Volume
5 Sealing Gland - Conax Model TG-24A-1-T With Teflon Seal
6 Molecular Sieve Trap - Varian Model 956-5003

Figure 5. Schematic of Pressure System to be Utilized With T-111 Alloy Biaxial Creep Capsule Pressure Transducer.

C1231-2

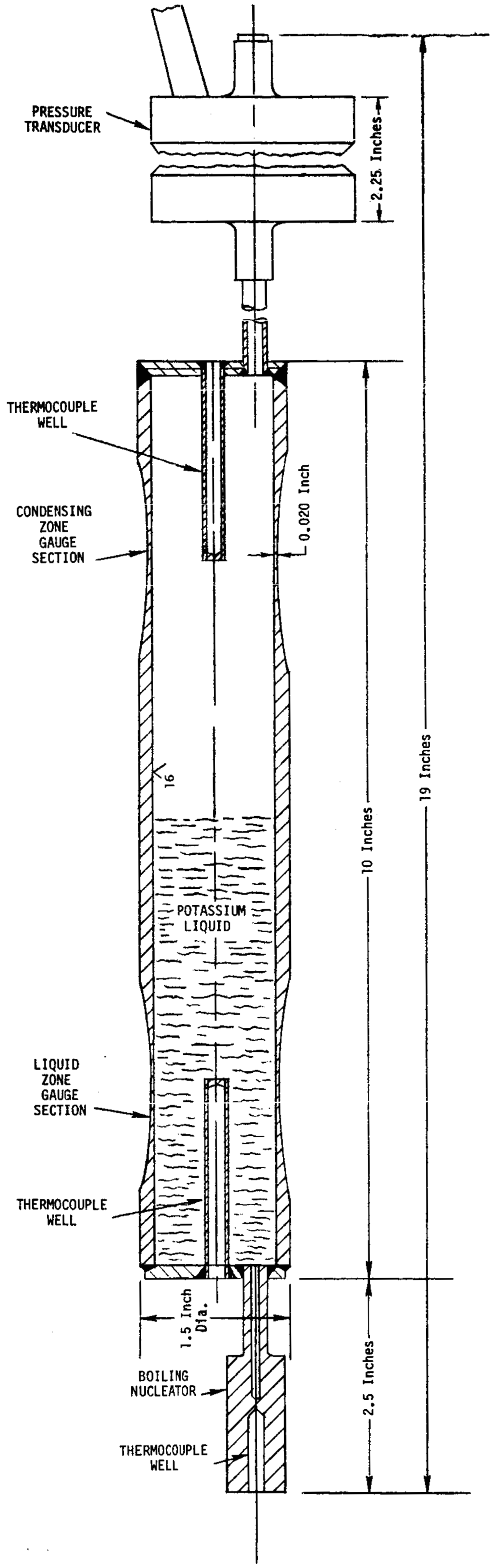


Figure 6. T-111 Alloy Biaxial Creep Capsule Design Showing Location Of Pressure Transducer.

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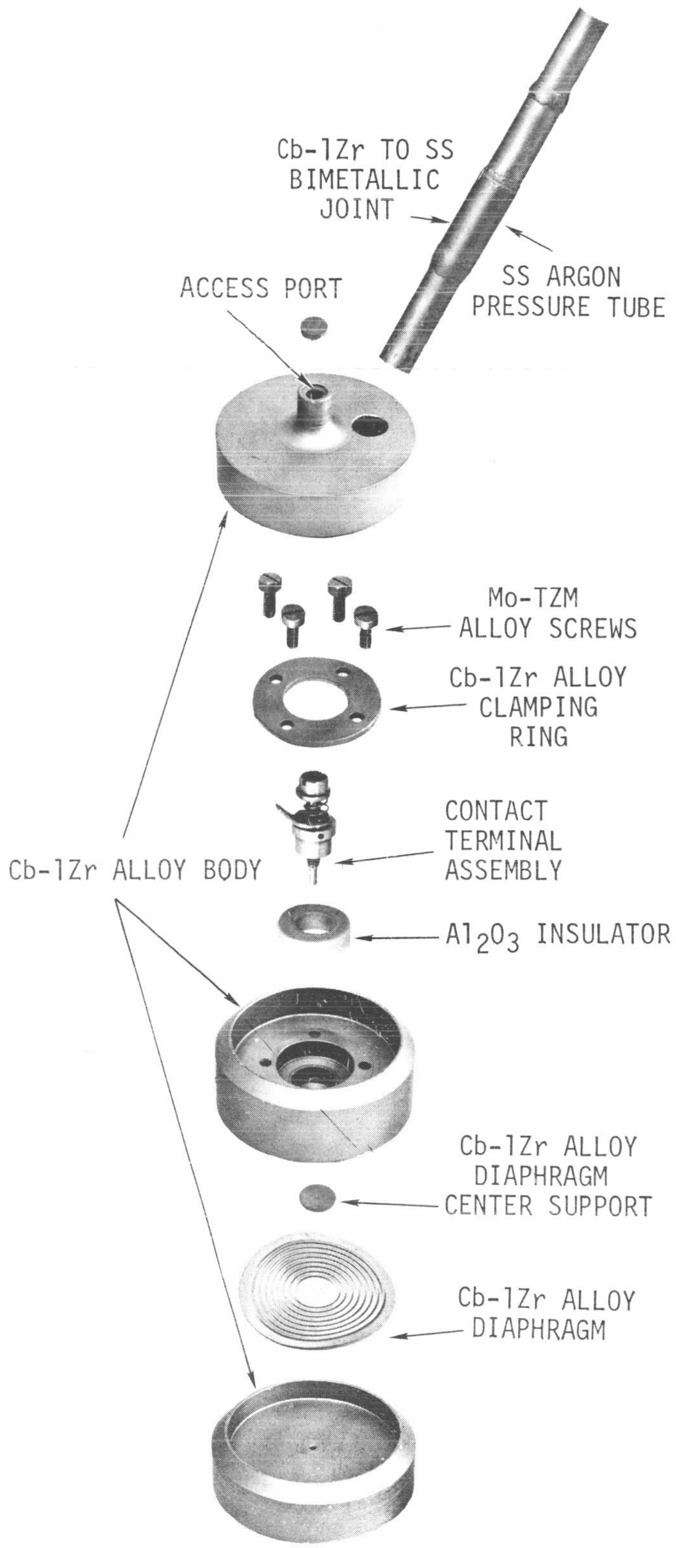

Figure 7. Components for Potassium Pressure Transducer Prior to Assembly.

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ERROR ANALYSIS

An error analysis to determine the anticipated accuracy of the creep data which will be obtained from both the uniaxial and biaxial creep tests on the T-111 alloy tubing has been completed. This analysis will allow a more realistic evaluation of any observed differences between the uniaxial and biaxial creep properties of the T-111 alloy. It also indicates which parameters contribute most significantly to the resulting creep data and, therefore, which parameter should be determined as accurately as possible.

The actual uniaxial and biaxial test data are compared by computing effective or equivalent uniaxial stress-strain data from the biaxial test results based on the von Mises theory of yielding as applied to pressurized tubes by C. R. Soderberg [3]. The basic assumptions of the von Mises theory are isotropy and constancy of volume during straining in the material of interest. The equivalent uniaxial data computed from the biaxial test results are then compared directly with the actual uniaxial test results. In this particular program, the effective stress levels in both the uniaxial and biaxial tests will be the same so that strain is the only variable. The remaining two parameters of time and temperature which are necessary for describing the creep properties of a material are measured directly during both the uniaxial and biaxial tests. Therefore, to obtain an accurate comparison of the uniaxial and biaxial stress-strain data the tests must be conducted at similar times and temperatures.

The theoretical effective or equivalent uniaxial stress for the biaxially stressed* T-111 alloy test capsule can be determined by the following equation [4]:

$$\sigma_e = \frac{\sqrt{3}}{2}\left(\frac{pr}{t}\right) \tag{1}$$

----

* Although the capsule is actually being triaxially stressed, the radial stresses are quite small and are, therefore, neglected for simplification.

where,

σ_e = effective uniaxial stress for the biaxially stressed test capsule

p = absolute internal pressure of capsule

r = mean capsule radius

t = capsule wall thickness in gauge section

The effective uniaxial strain for the biaxially strained capsule can be computed using the equation[4]:

$$\epsilon_e = \frac{\sqrt{3}\,\Delta d}{3r} - \frac{2\sqrt{3}\,pr\left(1-\frac{\mu}{2}\right)}{3tE} \qquad (2)$$

where,

ϵ_e = effective uniaxial strain for the biaxially strained test capsule

Δd = change in capsule diameter in gauge section for some interval of time.

r = mean capsule radius

p = absolute internal pressure of capsule

μ = Poisson's Ratio for material being tested

t = capsule wall thickness in gauge section

E = Young's modulus of elasticity for material being tested

The stress-strain data for the uniaxial tests are determined quite simply with the uniaxial stress being determined from:

$$\sigma = \frac{F}{A} \qquad (3)$$

where,

σ = uniaxial stress

F = total load

A = cross-sectional area of specimen in gauge length;

and the uniaxial strain is determined from:

$$\epsilon = \frac{\Delta L}{L} \qquad (4)$$

where,

ϵ = uniaxial strain

ΔL = change in gauge length for some interval of time

L = gauge length.

Based on creep properties reported by TRW Equipment Laboratories [5] for T-111 alloy, a set of hypothetical test conditions have been selected for the biaxially stressed test capsule which will result in an equivalent uniaxial creep of one-percent in 5000 hours. These conditions will be utilized to calculate the anticipated error in the stress-strain data to be determined in this program. The hypothetical test conditions and other necessary T-111 alloy property data along with their respective anticipated errors are given in Table I. Using the data in Table I and equations 1, 2, 3, and 4, the individual and combined effects of the various parameter errors on the accuracy of the equivalent uniaxial and actual uniaxial stress-strain data were computed. These effects are shown in Table II. It is obvious from the data in Table II that the use of a pressure transducer on the test capsule to determine the potassium vapor pressure (p) significantly reduces the possible error in determining the equivalent uniaxial stress (σ_e) in the capsule. Also accurate measurement of the capsule wall thickness (t) in the gauge section should be performed in an attempt to reduce the error introduced by this measurement in the equivalent uniaxial-stress data. The accuracy of the equivalent uniaxial strain (ϵ_e) is greatly dependent on the accuracy of the measured diameter change (Δd) during testing and, therefore, the diameter change should be measured as accurately as possible. The error introduced by the cross-sectional area in determining the uniaxial stress (σ) is caused by the small cross-sectional area of the uniaxial test specimens combined with the accuracy of measuring the area.

TABLE I. HYPOTHETICAL TEST CONDITIONS FOR BIAXIALLY STRESSED CAPSULE[a]

SYMBOL	PARAMETER	MEAN VALUE	ERROR
T	Temperature	2215°F	±1%
p	Potassium Vapor Pressure	268.6 psia	±14.3 psia[b] ±0.27 psia[c]
r	Mean Capsule Radius	0.660 in.	±0.001 in.
Δd	Capsule Diameter Change In 5000 Hours	0.012 in.	±0.0015 in.
t	Capsule Wall Thickness	0.020 in.	±0.001 in.
μ	Poisson's Ratio	0.35	±0.05
E	Young's Modulus (2215°F)	18×10^6 psi	$\pm 2 \times 10^6$ psi
F	Total Load for Uniaxial Test	153.5 lbs.	±0.1 lbs.
A	Cross-sectional Area of Uniaxial Test Specimen	0.020 in.^{2}	±0.001 in.^{2}
L	Gauge Length of Uniaxial Test Specimen	0.200 in.	±0.00005 in.
ΔL	Change In Gauge Length In 5000 Hours	0.002 in.	±0.00005 in.

(a) Selected to result in 1% uniaxial creep in 5000 hours.

(b) Error when determined as a function of temperature.

(c) Error when measured directly with pressure transducer.

TABLE II. EFFECT OF PARAMETER ERRORS[a] ON ACCURACY OF STRESS-STRAIN PROPERTIES

PARAMETER	MAXIMUM ERROR, %	
	FOR BIAXIAL TEST	
	σ_e[b]	ϵ_e[c]
p	±5.31[d], ±0.10[e]	±0.19[d], ±0.00[e]
r	±0.02	±0.09
t	±5.26	±0.19
Δd	-	±13.06
u	-	±0.09
E		±0.39
Total Effect	±11.00[d], ±5.50[e]	±14.20[d], ±14.00[e]
	FOR UNIAXIAL TEST	
	σ[f]	ϵ[g]
F	±0.06	-
A	±5.26	-
L	-	±0.03
ΔL	-	±2.50
Total Effect	±5.32	±2.53

[a] Given in Table I.

[b] Calculated using equation (1), σ_e (average) = 7676 psi.

[c] Calculated using equation (2), ϵ_e (average) = 0.01 in./in.

[d] Based on pressure being determined from temperature.

[e] Based on pressure being determined from pressure transducer.

[f] Calculated using equation (3), σ(average) = 7676 psi.

[g] Calculated using equation (4), ϵ (average) = 0.01 in./in.

IV. FUTURE PLANS

A. The 1.5-inch OD x 0.100-inch wall T-111 alloy tubing needed to make the capsules will be received and fabrication of the test capsules will be initiated.

B. Fabrication of the pressure transducer will be completed and calibration of the transducer will be initiated.

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(2) Ewing, C. T., Stone, J. P., Spann, J. R., Steinkuller, E. W. Williams, D. D., and Miller, R. R., "High-Temperature Properties of Potassium", September 24, 1965, NRL Report 6233, U. S. Naval Research Laboratory.

(3) Soderberg, C. R., "Interpretation of Creep Tests on Tubes", Trans. A.S.M.E. 63, 737, November (1941).

(4) Stallone, M. J., General Electric Company, Flight Propulsion Division, Evendale, Ohio, Private Communication, September 7 (1967).

(5) TRW Equipment Laboratories, Cleveland, Ohio, "Generation of Long Time Creep Data on Refractory Alloys at Elevated Temperature", Series of Quarterly Progress Reports for NASA Contract NAS 3-2545.

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